Touchdown Dynamics

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INTRODUCTION

Aircraft tire wear results from operating conditions are quite different from those encountered in land vehicles. One of the most important of these is touchdown, where the tire suddenly spins up from zero to a large angular velocity. This phenomenon is studied from both the analytical and experimental points of view. The analysis is basic, using elementary properties of the tire and wheel. It results in a new dimensionless description of the process. The experimental study consists primarily of small scale laboratory data, although limited full scale tire data is also presented.

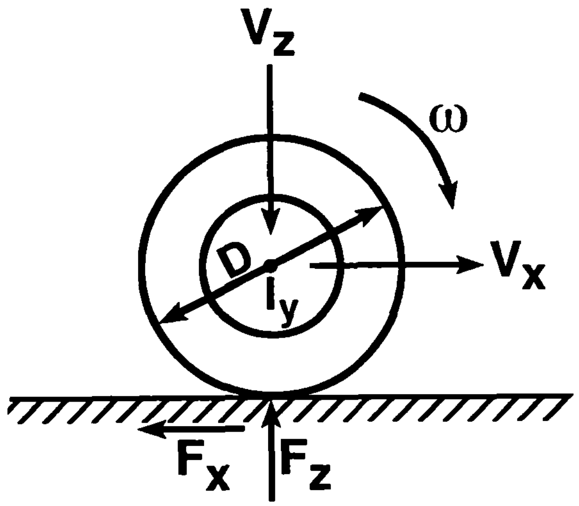
The data show increasing weight loss during touchdown as the dimensionless severity increases.

[1]This work was conducted under USAF Contract F33657-92-C-2167. Mr. Paul Wagner was the USAF project engineer.

WHEEL AND AIRCRAFT PARAMETERS

The analysis assumes that a tire and wheel are attached to the axle of an aircraft moving at forward velocity V_x with constant sink rate V_z, with the wheel at zero angular velocity ω at time t=0 of initial contact. The tire of diameter D is attached to a wheel with brake rotor, all of which have polar moment of inertia I_y. The vertical and horizontal contact forces are F_z and $F_x = \mu F_z$, respectively, where the friction coefficient μ is assumed constant during spin-up.

The tire is assumed to be rigid torsionally, but to be a linear spring in the vertical direction, so that $F_z = K_z \delta_z$ where δ_z is vertical deflection and K_z is the vertical spring rate. The contact area is controlled by tire deflection.



Wheel and aircraft parameters

F_x = tire horizontal force
V_x = landing speed, assumed constant
V_z = sink rate, assumed constant
I_y = polar inertia of tire, wheel and brake
K_z = tire vertical spring rate
μ = friction coefficient
ω = tire angular velocity
D = tire diameter
F_z = tire vertical force

Figure 1 - Wheel and tire parameters.

TOUCHDOWN ANALYSIS

The analysis is based on evaluating the integral of contact area times sliding distance as a measure of the volume of tread material lost by abrasion and/or ablation.

Assuming the volume of a tire is approximately proportional to the square of the diameter and the first power of the tire width, the resulting dimensionless loss of volume during touchdown is given in Fig. 2. This new parameter is called Touchdown Severity and is postulated to be a dimensionless measure of volume lost, as shown in Fig. 2.

The friction coefficient μ is not considered further in this analysis.

Assumptions:

(a) V_x, V_z are constant during spin-up.

(b) μ is constant during spin-up.

(c) Contact patch area is proportional to tire deflection.

(d) Wear is the integral of contact patch area x sliding distance.

Result:

$$\frac{\text{volume lost}}{\text{volume of tire}} = \frac{1}{\mu}\sqrt{\frac{D}{W}}\left[\frac{V_x^2 I_y}{D^4 K_z}\right]$$

V_x = touchdown speed

I_y = polar moment of inertia

D = tire diameter

K_z = tire vertical stiffness

$$\text{Touchdown Severity} = \left[\frac{V_x^2 I_y}{D^4 K_z}\right]$$

A dimensionless number.

Figure 2 - Touchdown Severity Index.

LABORATORY TESTING

Based on the concept of dimensionless parameters, small scale tires were fabricated from Buna N (nitrile) O-rings mounted on nylon pulleys. These miniature wheels were mounted on an axle, which in turn could be forced into sudden touchdown to a rotating abrasive disc via a solenoid and a controlled timing circuit. By adjusting the point of touchdown on the disc from an inner position to the outer edge, touchdown velocity could be varied from 100 to slightly over 200 feet per second. By using inertia rings attached to the nylon wheel, polar moment of inertia could be varied. Using both of these as variables, the dimensionless severity index could be varied from values of approximately 10 up to 200.

The timing circuit was adjusted to bring the wheel-tire into contact with the spinning abrasive disc for 0.4 sec., a time sufficient to spin up, and then to retract it for 10 sec., allowing the wheel to spin down to rest by bearing friction effects.

Ten touchdowns were used to make one complete set at a given condition. Weight of the tire-wheel was recorded both before and after the ten runs using a sensitive laboratory balance.

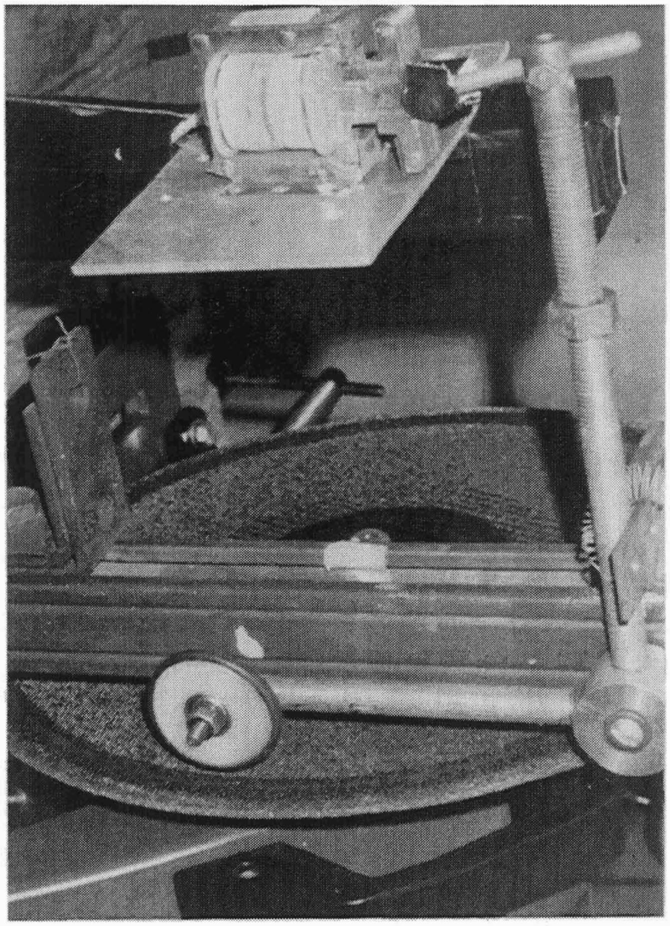


Figure 3 - Small scale test apparatus for touchdown wear.

LABORATORY DATA ON BUNA N (NITRILE)

Using the laboratory apparatus described on the previous page, data on Buna N (nitrile) rubber was obtained over a very wide range of values of the severity index, up a value of nearly 200. The values obtained were plotted as percent weight loss of the small tire due to ten touchdowns vs. severity index number. The data show a relatively smooth increase in weight loss as severity index increases.

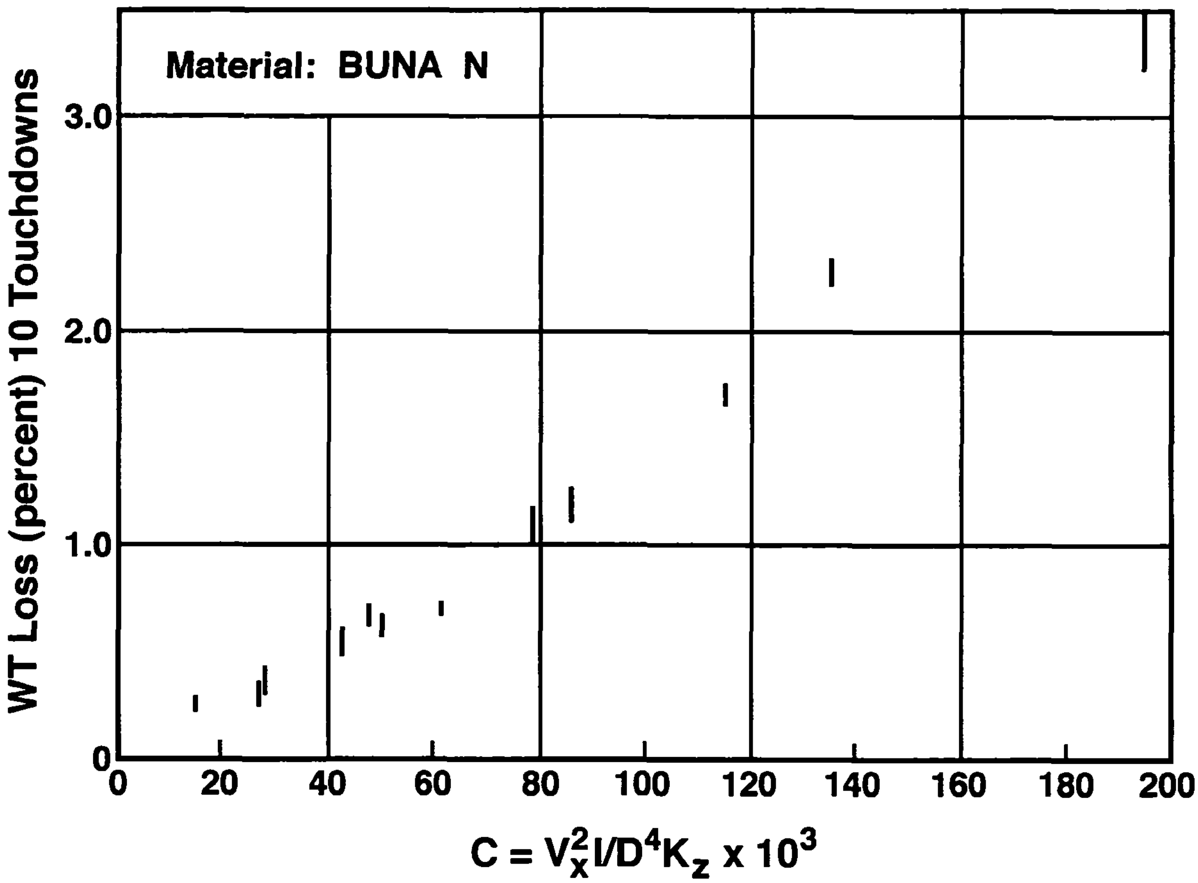


Figure 4 - Percent weight loss vs. severity index.

LABORATORY DATA ON NR AND NR-SBR COMPOUNDS

Further data was obtained by fabricating small scale tires from compounds similar to those used in commercial aircraft tire treads. These were plotted against increasing severity index, and compared with the Buna N data previously obtained. As might be expected, the commercial compounds exhibited less wear. Two compounds were studied. The first, denoted No. 3 and plotted in Fig. 5 as circles, is a 100% NR compound. The second, denoted No. 13, is a 65% NR-35% SBR compound. They appear to be very close in their resistance to touchdown wear, but both are clearly more resistant than nitrile.

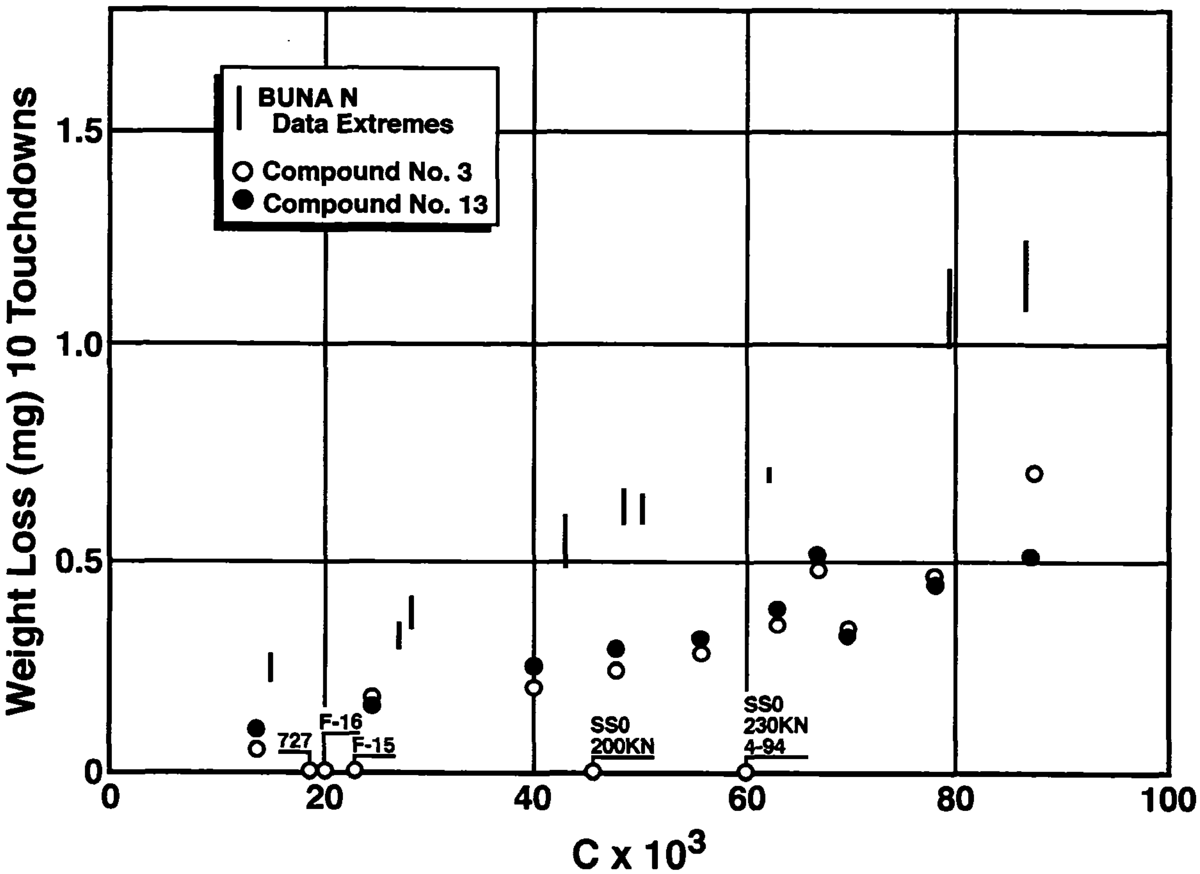


Figure 5 - Weight loss at ten touchdowns vs. severity index.
Three compounds.

ANALYSIS OF SHEAR STRESS

It is known that at high values of the severity index cutting of the tread can occur. In order to examine the information available from this simplified analysis, the shear stress caused by touchdown is calculated by forming the ratio of the tangential force to the contact area. The resulting value of shear stress is probably as good a measure of cutting as is available. The resulting expression is primarily dependent on tire vertical stiffness K_Z, which in turn is controlled to a great extent by inflation pressure. This implies that cutting is most severe at high inflation pressures, but gives little other insight to the phenomenon, since there is in this analysis no simple means for defining the counter surface.

$$\textbf{Contact Area } A = \pi\delta_z\sqrt{\omega D} = \pi V_z\, t\sqrt{wD}$$

$$\textbf{Tangential Force } F_x = \mu F_z = \mu\, V_z\, t\, K_z$$

$$\textbf{Shear Stress} \quad \tau_x = F_x / A = \frac{\mu}{\pi}\ \frac{K_z}{\sqrt{wD}}$$

Figure 6 - Shear stress as a measure of cutting.

SPIN DOWN TEST ANALYSIS

In order to utilize existing spin down data, an analysis was conducted on the problem of a spinning tire, held at zero forward velocity, allowed to drop onto a rigid fixed surface. The result showed that the ratio of tread loss to tire volume is controlled by the same dimensionless severity index as obtained previously. In this particular case, a modified spin down experiment was considered in which the tire deflection was limited to preset value $\bar{\delta}$ by the use of air cylinders simulating aerodynamic lift. The specific value of $\bar{\delta}$ does not appear in the resulting volume loss. The rotational velocity decreases linearly with time in this analysis, as shown in Fig. 7.

Modified Spin Down Test

$\bar{\delta}$ = allowable tire deflection

Other assumptions same

$$\frac{V_L}{V_T} = \frac{1}{\mu}\sqrt{\frac{D}{W}}\left[\frac{V_x^2 I}{D^4 K_z}\right]$$

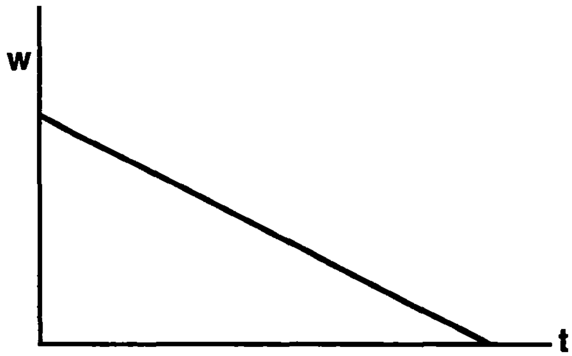


Figure 7 - Volume loss and spin down speed.

SPIN DOWN TEST SPEED

Full-scale spin down tests were conducted to evaluate tire wear under this condition. Instrumentation was installed to measure wheel and tire rotational speed during the test, and typical values of this data are shown in Fig. 8. The wheel speed decreases almost linearly with time, and this is in good agreement with the result of the analysis shown in Fig. 7.

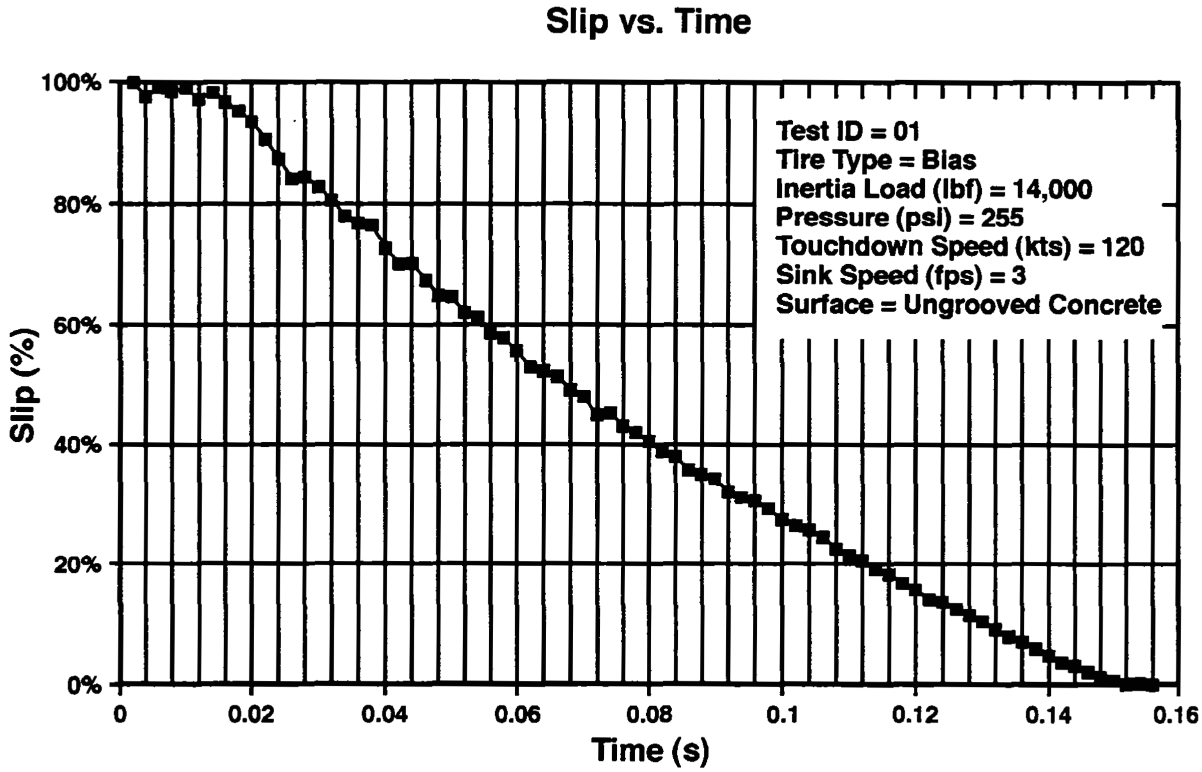


Figure 8 - Wheel speed vs. time on spin down test.

WEIGHT LOSS VS. TOUCHDOWN SEVERITY

Using data from the full-scale drop tests, expressed as percent of tire weight for ten touchdowns, and from the small-scale NR and NR-SBR laboratory tires, a single combined plot of data can be produced as a function of touchdown severity. This shows that the resulting loss values are similar in magnitude, although the full-size data exhibits some scatter. The mass of the small tire was 2.4 grams, while that of the full-size tire was over 18,000 grams. Both bias and radial tires were used in the full-size test plan.

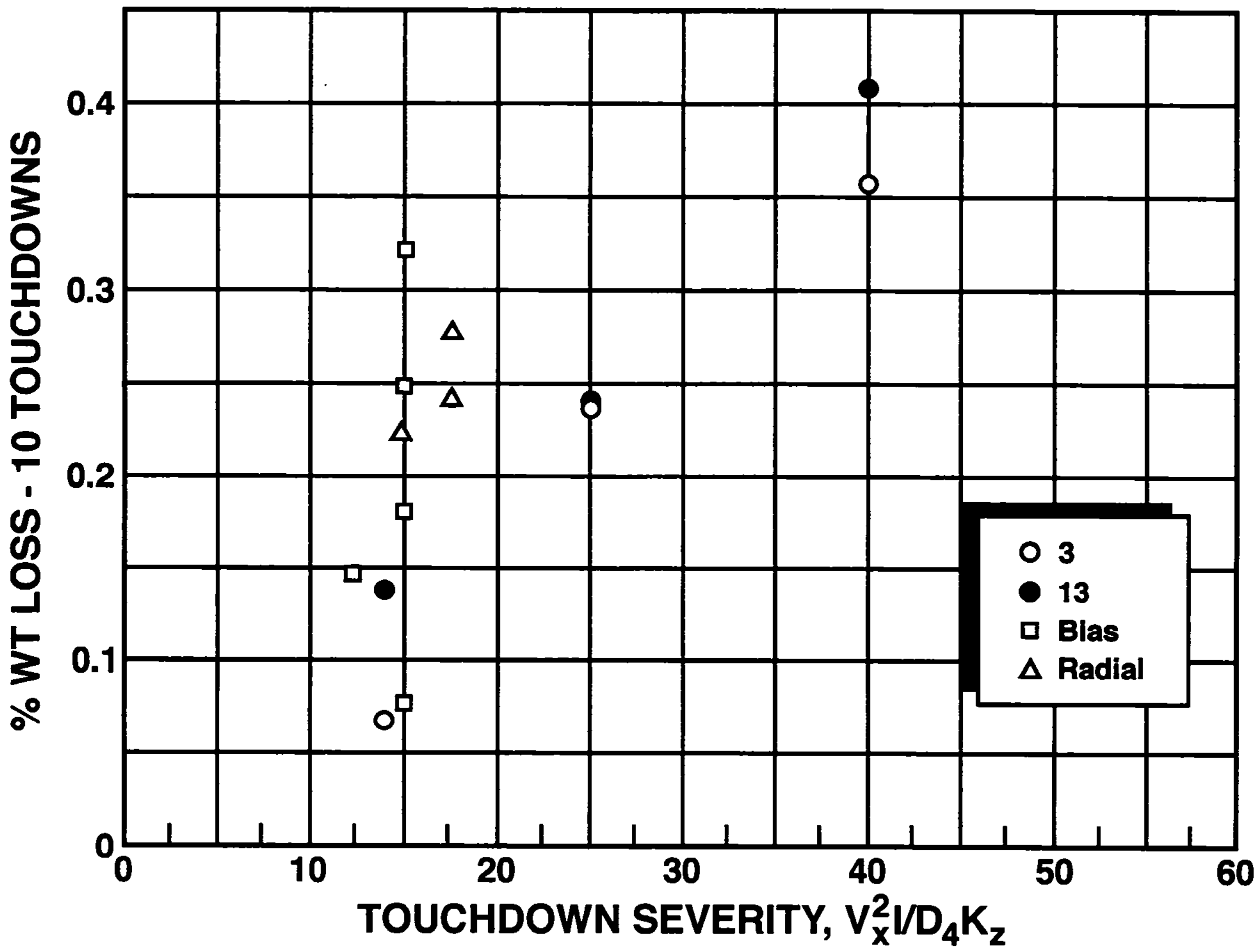


Figure 9 - Weight loss for both small-scale and full-size tires vs. touchdown severity index.

SEVERITY INDEX

The touchdown severity index may be useful as a measure of the damage (abrasion, ablation or cutting) which is experienced by a tire during spin-up. Little reliable full-size tire data is available as yet to assess the validity of such predictions, but it is hoped that such data may be obtained in the future.

This index may be interpreted as the ratio of the spin-up kinetic energy to the potential energy of the deflected tire, as shown in Fig. 10.

$$\left[\frac{V_x^2 I}{D^4 K_z}\right] = \left(\frac{V_x}{D}\right)^2 I \Big/ \left(D^2 K_z\right) = \frac{\text{K.E. of Tire \& Wheel Assembly}}{\text{P.E. of Deflected Tire}}$$

Figure 10 - Touchdown severity index.